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Isothermal Martensitic and Pressure-Induced (Delta) to (Alpha)' Phase Transformations in a Pu-Ga Alloy

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Isothermal Martensitic and Pressure-Induced δ to α' Phase Transformations in a Pu-Ga Alloy

ICOMAT-08
July 1, 2008
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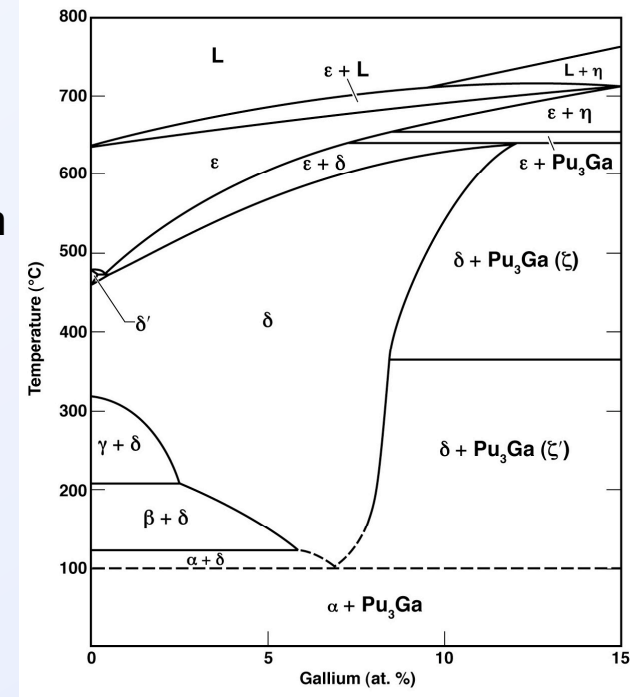
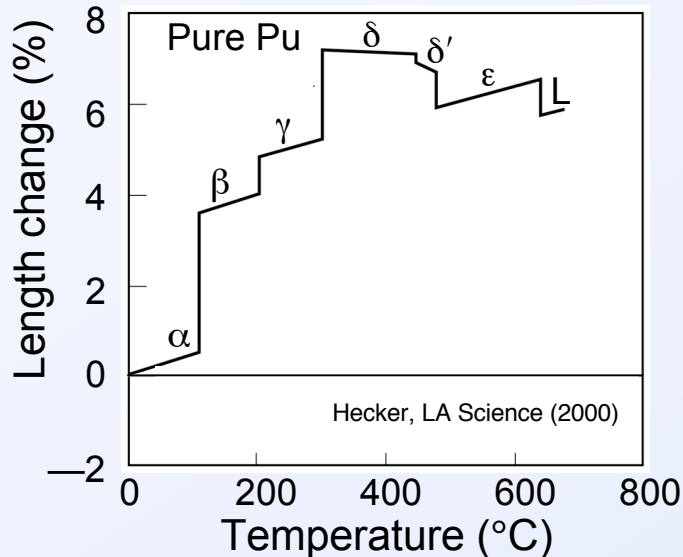
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Understanding the phase transformations remains as one of the significant Pu metallurgical challenges

- Equilibrium phase diagram
- 5 allotropic phase transformations
- Phase transformations and phase stability
 - The $\delta \rightarrow \alpha'$ isothermal martensitic transformation
 - The $\delta \rightarrow \alpha'$ transformation under pressure



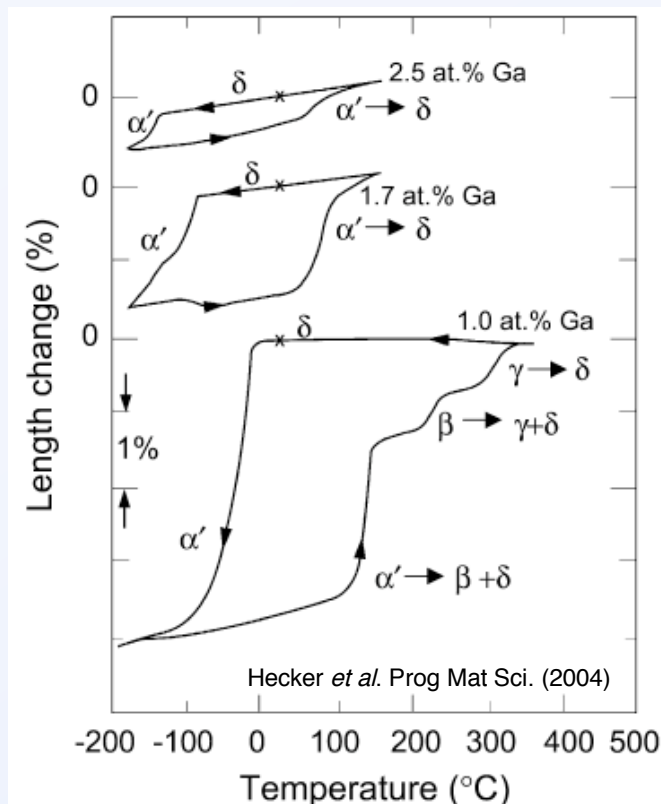
The δ -phase retained to room temperature is metastable

Timofeeva (2003) estimated 10,000 years to decompose

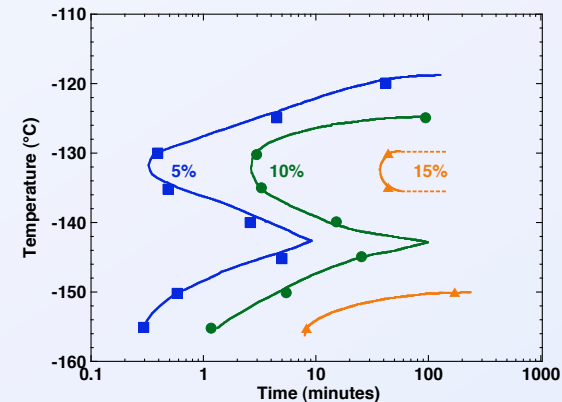
Low-temperature $\delta \rightarrow \alpha'$ martensitic transformation

Upon cooling to sub-ambient temperatures, δ transforms to α' via an isothermal martensitic transformation

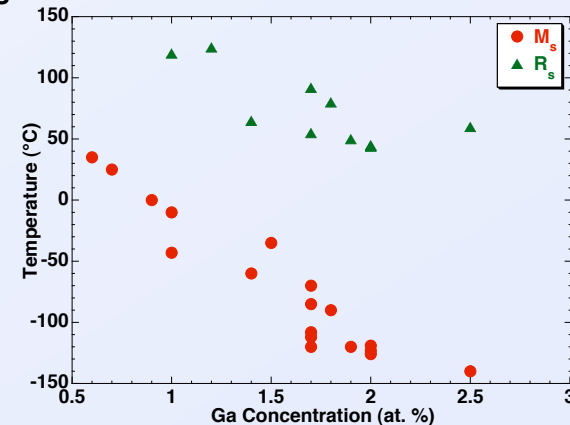
The $\delta \rightarrow \alpha'$ isothermal martensitic transformation can be induced with continuous cooling experiments



The TTT curve for the isothermal $\delta \rightarrow \alpha'$ transformation has double-C curve kinetics



The martensite start temperature, M_s , is a function of Ga content



Like the δ -phase at room temperature, α' is also metastable



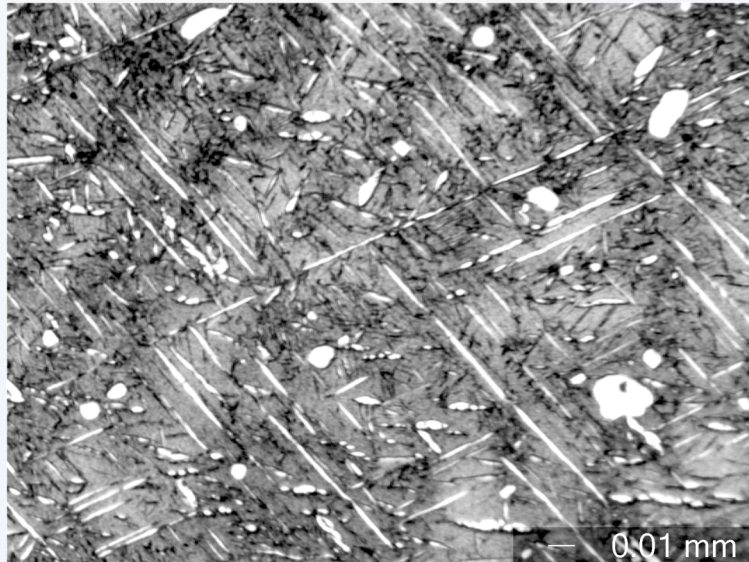
Low-temperature $\delta \rightarrow \alpha'$ martensitic transformation

The α' particles that form from the isothermal martensitic transformation appear as lathes in optical microscopy

-120°C/4 hours

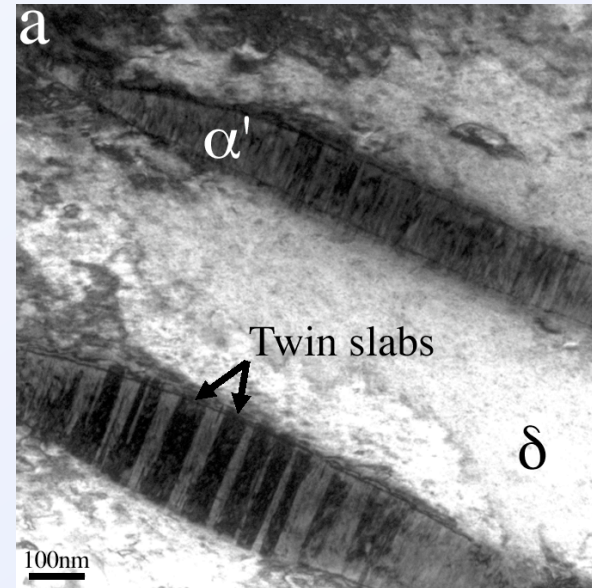
Pu - 2.0 at.% Ga

-120°C/10 hours



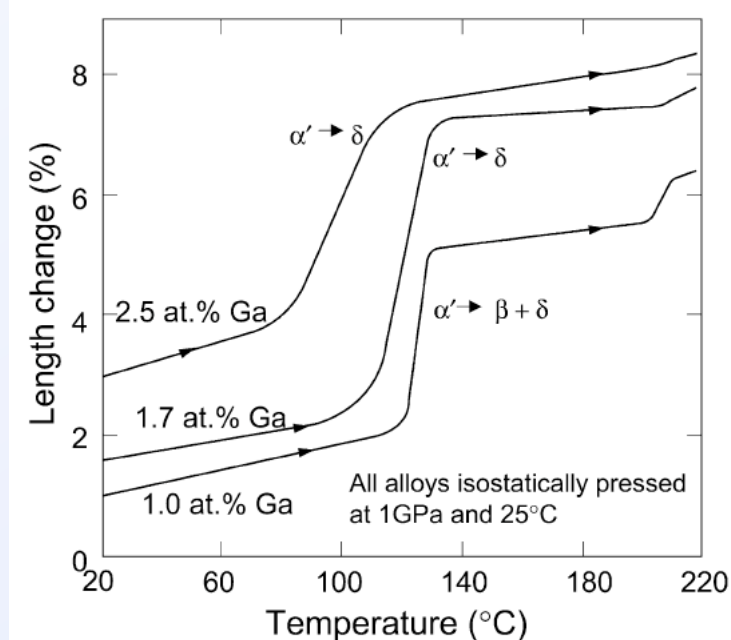
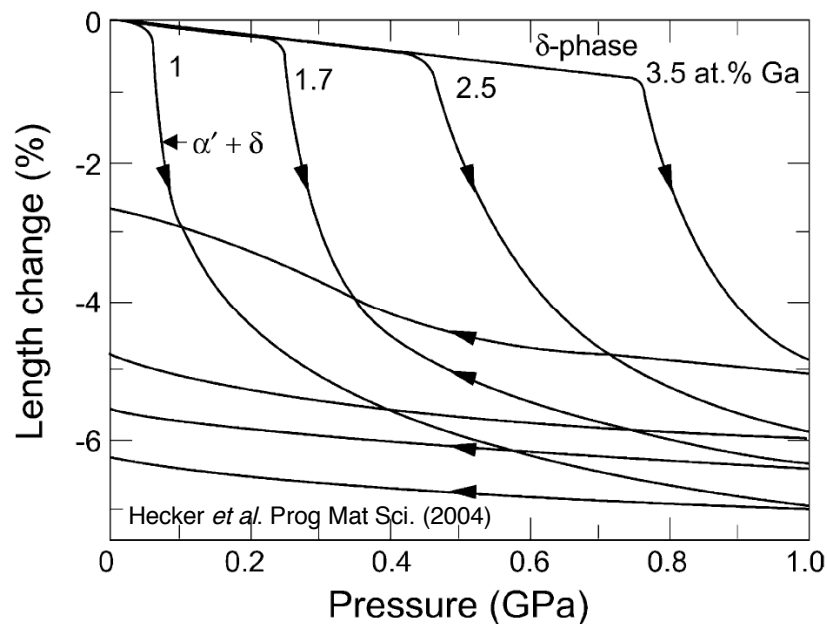
Partially transformed
($\delta + \alpha'$ phases)

The $\delta \rightarrow \alpha'$ isothermal martensitic transformation goes to ~ 25% completion



- The orientation relationship between α' and δ is: (Zocco *et al.* Acta Met. 1990)
 $(111)_{\delta} \parallel (020)_{\alpha'}$
 $[-110]_{\delta} \parallel [100]_{\alpha'}$
- α' particles consist of 2 variants rotated 60° around $\langle 020 \rangle_{\alpha'}$
- TEM shows $(205)_{\alpha'}$ twinning as a lattice invariant deformation mode

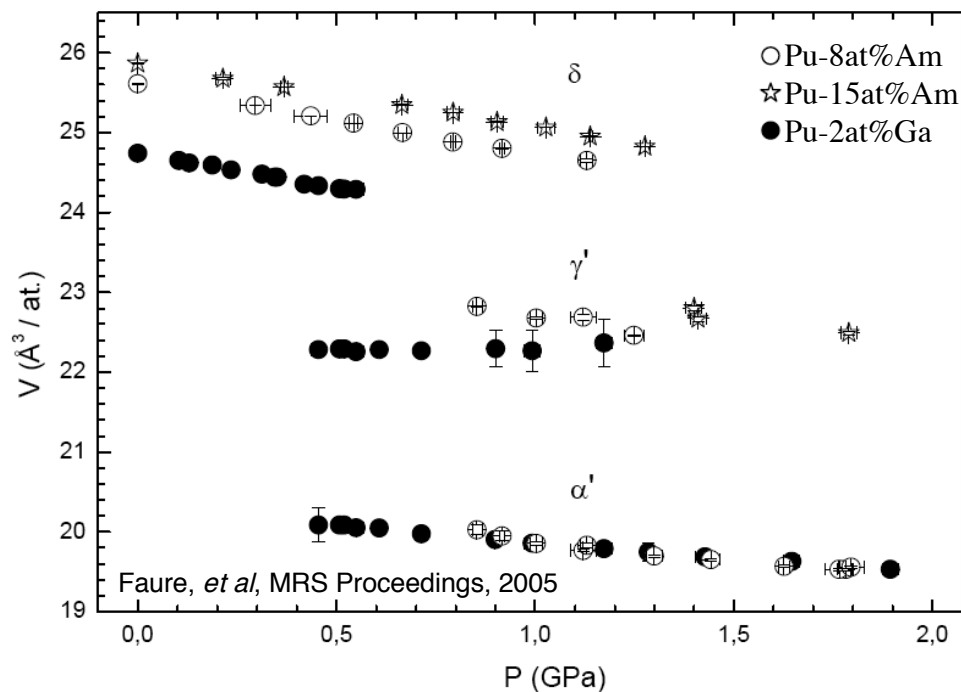
The $\delta \rightarrow \alpha'$ transformation and reversion characteristics are a strong function of composition



- Under pressure, Pu - Ga alloys transform directly to α' and undergo either a direct ($\alpha' \rightarrow \delta$) or indirect ($\alpha' \rightarrow \beta + \delta \rightarrow \gamma + \delta \rightarrow \delta$) reversion
- Reversion characteristics are similar to those in thermally-induced transformations

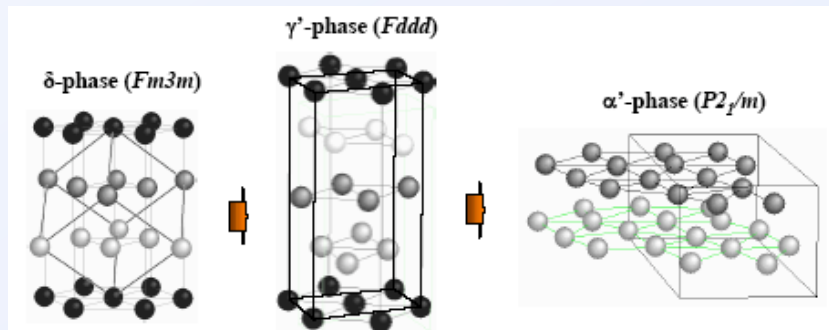
Pressure-induced $\delta \rightarrow \alpha'$ martensitic transformation

Diamond anvil cell experiments on a Pu - 2 at.% Ga alloy reveal $\delta \rightarrow \gamma' \rightarrow \alpha'$ transformation sequence



In the DAC, Pu - 2 at.% Ga transforms through the sequence $\delta \rightarrow \gamma' \rightarrow \alpha'$

Zukas *et al.* (1981) report Pu - 2 at.% Al alloys transform through the sequence $\delta \rightarrow \beta' \rightarrow \alpha'$

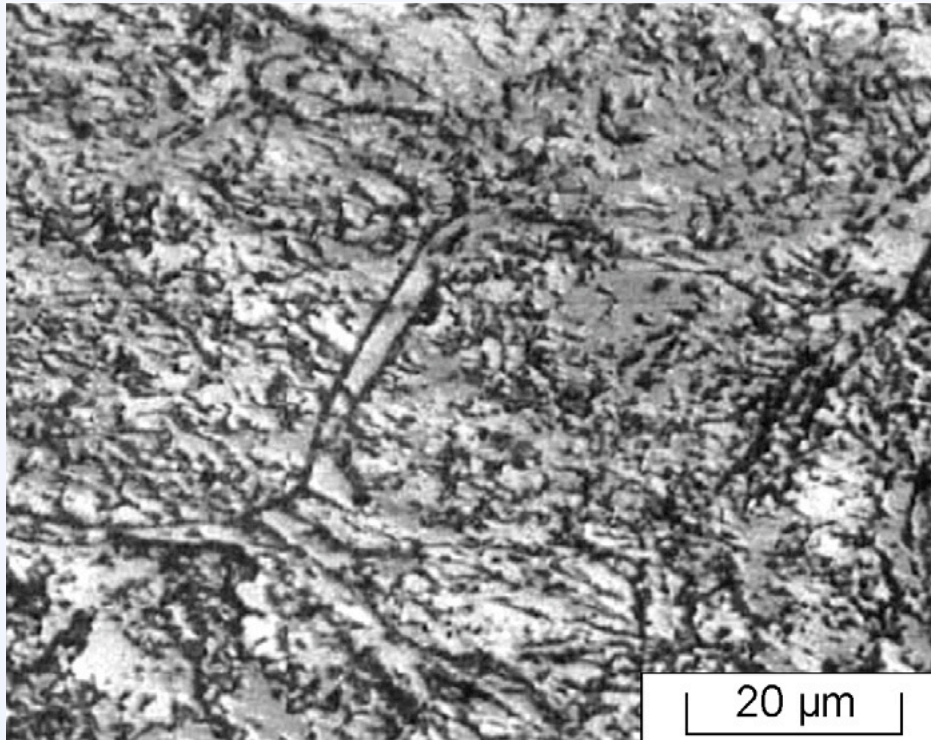


Faure *et al.* MRS Proceedings (2006)

Pressure-induced $\delta \rightarrow \alpha'$ martensitic transformation

Upon cooling, Harbur reported that a 0.68 at.% Ga alloy has a density intermediate between δ and α phases

Harbur, JALCOM (2007)



After compressing to 1 GPa

Alloy	% α'	% δ	% amorphous
1.0 at.% Ga	87	0	13
1.7 at.% Ga	66	0	34
2.5 at.% Ga	68	12	20

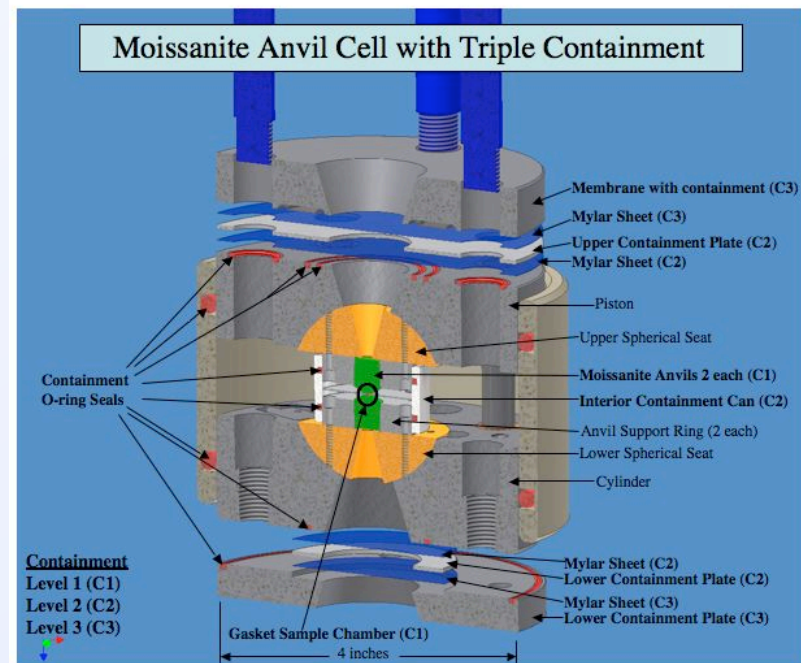
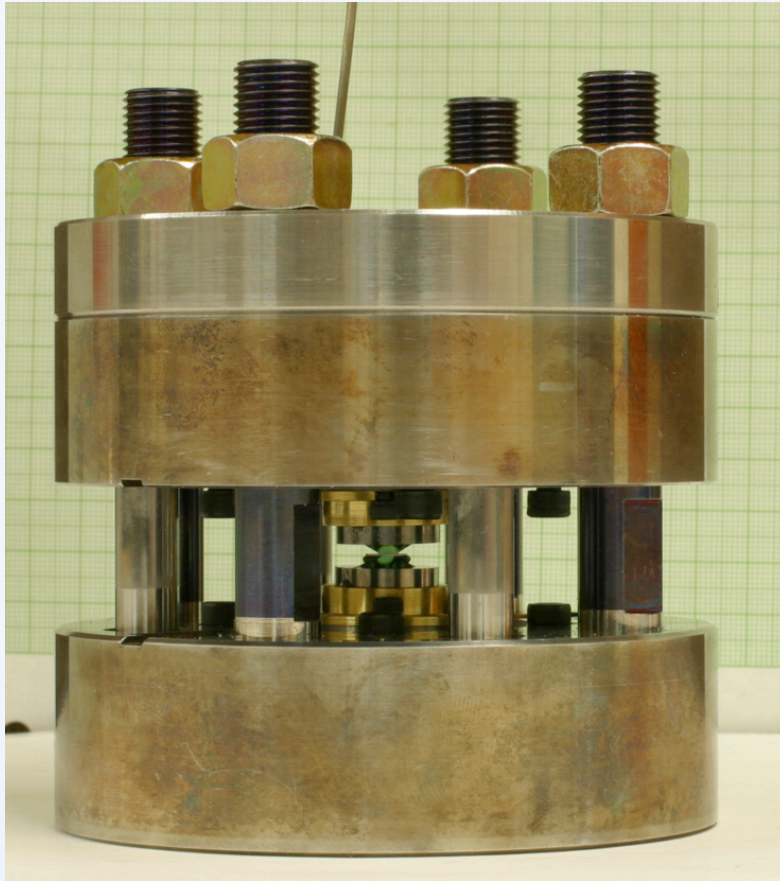
Harbur, JALCOM (2007)

Harbur proposes that the δ phase transforms to α' + amorphous phase

- on cooling low solute alloys
- under pressure

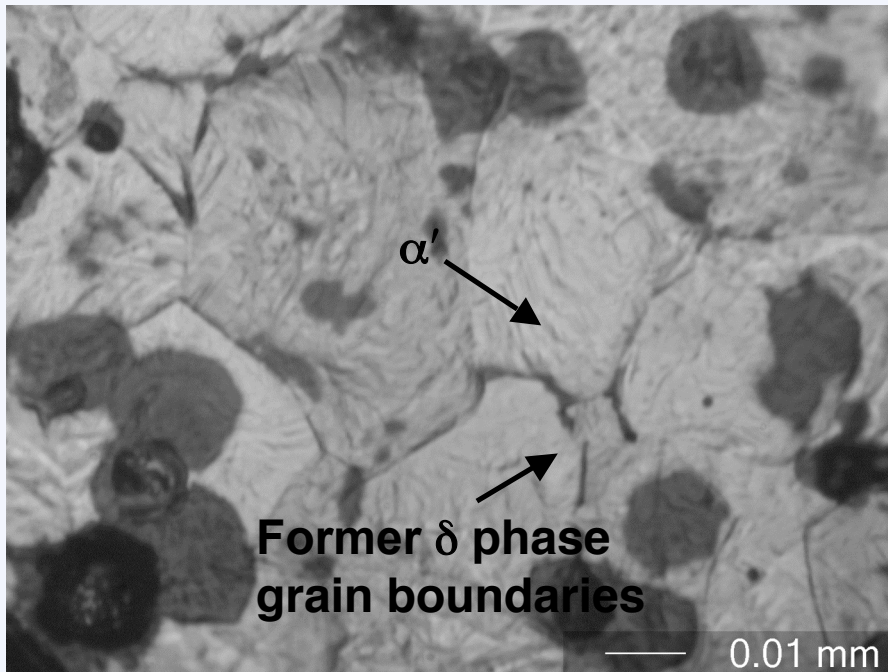
Pressure-induced $\delta \rightarrow \alpha'$ martensitic transformation

We are coupling low pressure recovery experiments with TEM to elucidate the mechanism and morphology

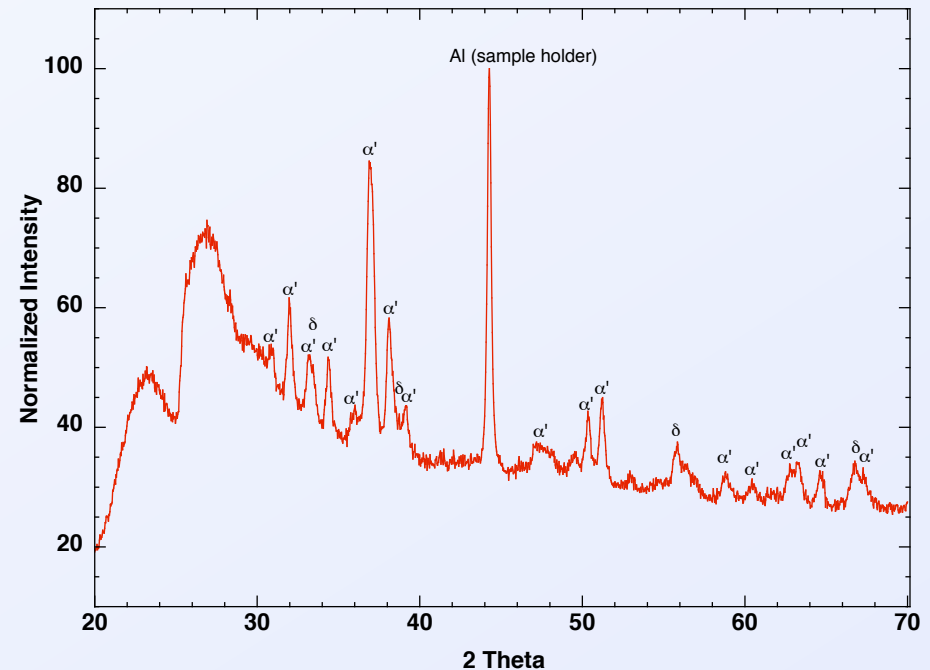


2.3 mm diameter specimens are slowly compressed to 1 GPa in the large volume moissanite anvil cell

Optical microscopy and x-ray diffraction of the compressed specimen reveals α' and δ phases



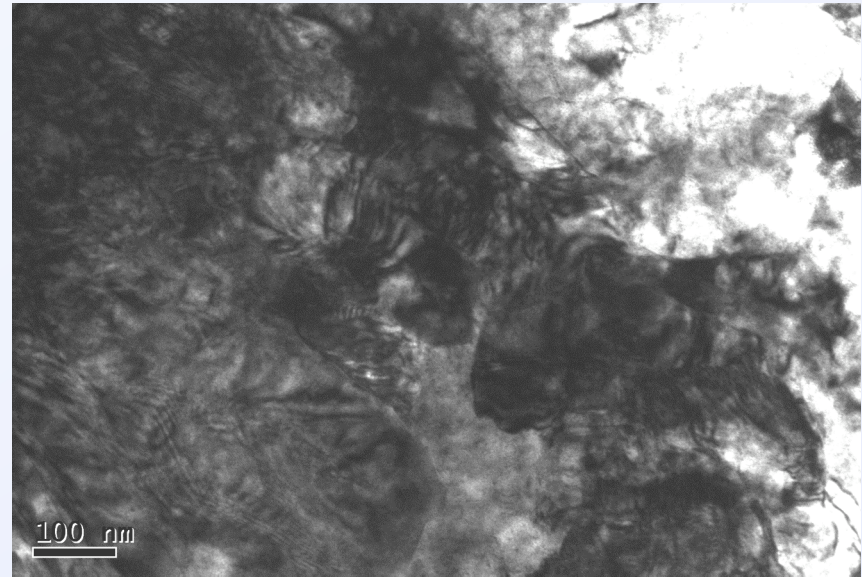
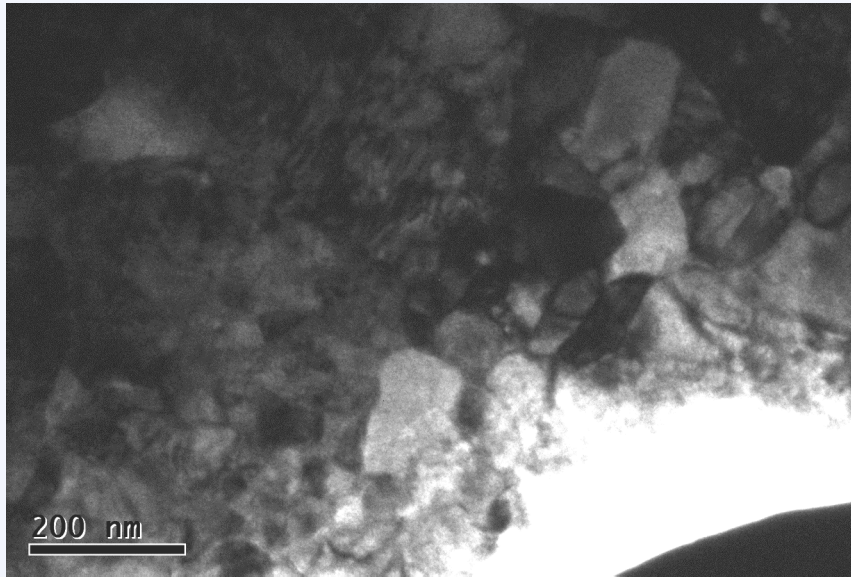
Optical microscopy does not have the resolution to differentiate between phases



X-ray diffraction experiments and simulations do not indicate the presence of an amorphous phase

Pressure-induced $\delta \rightarrow \alpha'$ martensitic transformation

The pressure-induced microstructure does not exhibit typical martensitic features



Pressure-induced $\delta \rightarrow \alpha'$ transformation

Average α' grain size ~ 100 s nm, 10 – 20% δ

Implies nucleation-dominated mechanism

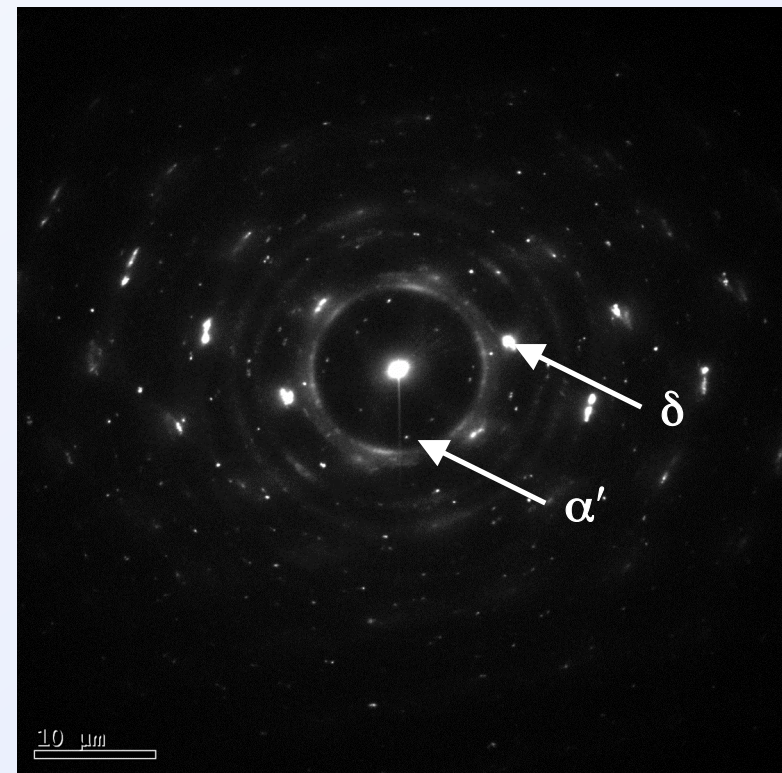
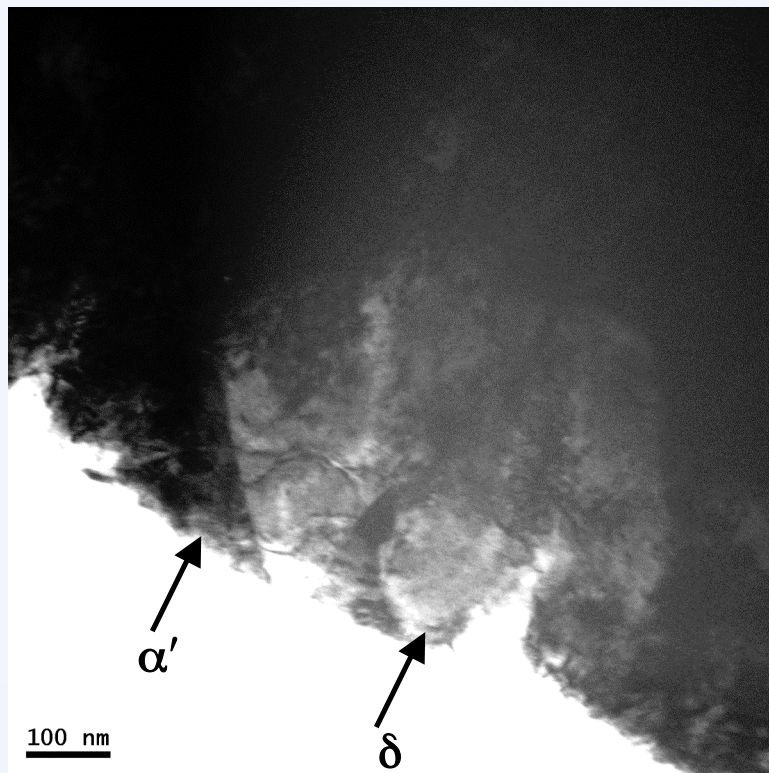
Low-temperature-induced $\delta \rightarrow \alpha'$ isothermal martensitic transformation

Average α' particle size ~ 1000 s x 10,000s nm

Implies nucleation-limited mechanism (strain)

Pressure-induced $\delta \rightarrow \alpha'$ martensitic transformation

Preliminary TEM reveals fine-grained α' and small amounts of δ – no evidence of an amorphous phase



10 – 20% δ phase is observed dispersed between the α' grains
High dislocation density
No apparent orientation relationship (yet)

The isothermal martensitic and pressure-induced microstructures differ significantly

- Low temperature isothermal $\delta \rightarrow \alpha'$ transformation
 - Nucleation is limited
 - Lath-shaped particles form
 - Intermediate phases are possible
- Pressure-induced $\delta \rightarrow \alpha'$ transformation
 - Nucleation dominates
 - Very fine grain size results
 - No evidence of the amorphous phase
 - Intermediate phases are likely

